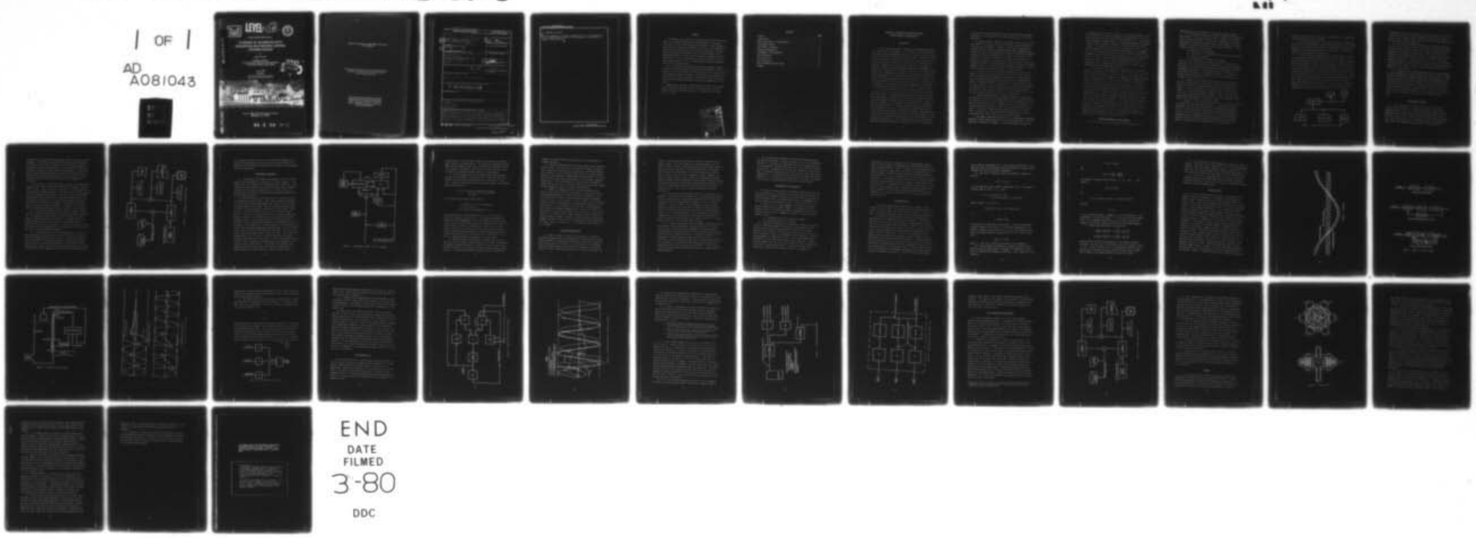
AD-A081 043 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 9/2
PLANNING OF AUTOMATED DATA ACQUISITION AND PROCESS CONTROL SYST--ETC(U)
JAN 80 R H MULTER
UNCLASSIFIED WES/MP/HL-80-1

1 OF 1

AD A081043



END
DATE
FILMED
3-80
DDC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL II

MISCELLANEOUS PAPER HL-80-1

PLANNING OF AUTOMATED DATA ACQUISITION AND PROCESS CONTROL SYSTEMS (ADACS)

by

Roger H. Multer

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

January 1980

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper HL-80-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 PLANNING OF AUTOMATED DATA ACQUISITION AND PROCESS CONTROL SYSTEMS (ADACS).		5. TYPE OF REPORT & PERIOD COVERED 9 Final rep[redacted]t,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Roger H. Multer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE 11 Jan[redacted]80
		13. NUMBER OF PAGES 38
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 43		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

14 WES/MP/HL-80-1

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Automated Data Acquisition and Control Systems
Automation
Control equipment
Data acquisition
Process control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report deals with the planning of Automated Data Acquisition and Control Systems (ADACS) and is written to introduce the general engineering and management audience to the types of considerations which must be addressed for successful implementation of such systems. Brief discussions are presented on such topics as basic system requirements, minicomputer components, systems implementation, programming of minicomputers, data acquisition, process control,

(Continued)

over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411389

20. ABSTRACT (Continued).

and data transmission. The ADACS developed for use at the Chesapeake Bay model, a large hydraulic model of the Chesapeake Bay, is discussed as an example of WES experience.

Preface

The material presented herein resulted primarily from work funded under the Computation and Analysis Program through the work unit, "Development of Real Time Operating Systems Models." This program is sponsored by the Computation and Analysis Section, General Engineering Branch, Engineering Division, Office, Chief of Engineers. The Automated Data Acquisition and Process Control System (ADACS) for the Chesapeake Bay Model briefly discussed herein was developed under the sponsorship of the U. S. Army Engineer District, Baltimore. The research was performed at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

Dr. R. H. Multer of the Math Modeling Group, Hydraulic Analysis Division, prepared this report under the general supervision of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. M. B. Boyd, Chief of the Hydraulic Analysis Division. Personnel from the Estuaries Division and the Instrumentation Services Division were major participants in the ADACS development work which provided the foundation for this report.

Commanders and Directors of WES during the conduct of this study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

Contents

PLANNING OF AUTOMATED DATA ACQUISITION AND PROCESS CONTROL SYSTEMS (ADACS)

Introduction

1. This report deals with the planning of Automated Data Acquisition and Control Systems (ADACS). It is written to introduce the general engineering and management audience to the types of problems which must be considered in designing satisfactory ADACS. A variety of topics are discussed in this report. The reader may find the discussion heterogeneous; and he will hopefully become aware that a relatively broad spectrum of managerial and technical considerations is involved in planning a system. Many data processing tasks may be programmed in a higher level language such as FORTRAN or COBOL and the necessary systems analysis and programming accomplished with only a minimal knowledge of how the equipment and its operating software function. ADACS are different because they require an intimate knowledge of the hardware, the operating software, and the special devices connected to the system. If our experience is any barometer, extensive adaptation of the software and hardware may be required in the development of a viable system.

2. A decade ago, ADACS were relatively expensive and the digital processors used in them tended to be far less powerful than the equipment now available. Systems hardware was kept to an absolute minimum and as much work as possible was centralized onto available equipment. Times have changed; equipment is much less expensive, more compact, and much more powerful. As a consequence, decentralization of equipment and the accomplishment of a broader spectrum of data processing tasks are economically justified. This presents a problem because highly skilled personnel are required to implement an ADACS. Fractionalization of the limited technical skill which would result from attempting to use a multiplicity of unlike data processing systems would represent a major managerial miscalculation. This distributed data processing concept, described subsequently, provides a reasonable solution to the problem.

It is felt that a generalization of this concept would be potentially applicable to other specialized data processing needs of the Corps of Engineers.

3. Modern Hydraulic Research uses Automated Data Processing Equipment (ADPE) in a variety of ways including ADACS, Numerical Modeling, Data Analysis, and Graphics. Because of the specific requirements, different ADPE is needed for different tasks. The fundamental point, however, is that to the maximum extent possible, the different hardware systems must function homogeneously in support of the research. The situation is the same in other activities where ADACS are employed. Hence, all of the types of data processing and the peculiarities of the equipment available or needed for doing it must be considered in systems planning. Care in this respect impacts both upon the success of a given project and upon the overall efficiency of an organization.

4. Several topics are discussed in subsequent sections of this report. Each of the sections is intended to cover material which is felt to be important to the favorable implementation of minicomputers in the research and development environment where the fundamental emphasis is on experimentation in which process control and data acquisition are essential. None of the discussions is intended to be complete or exhaustive of all of the alternatives which could be reasonably utilized in a given situation. Some of the concepts explored are valid in other applications with quite different circumstances.

5. Discussed specifically in subsequent sections are Automated Data Acquisition and Control Systems (ADACS) in which a digital computer or computers are used to control apparatus used in an experimental setup and in the acquisition of data. Similar, but distinct, applications would be data acquisition as is needed in flood forecasting and process control as would be encountered in the automated control of a power plant. In particular, these applications have some but not all of the requirements of an ADACS, which is used in an R&D program.

6. Minicomputer applications which the U. S. Army Engineer Waterways Experiment Station (WES) deals with on a continuing basis are in the research and development environment. In this environment the specifics

of equipment utilization vary on a more or less continuing basis. Hence, the requirement for software development is continual and in the long term relatively expensive (often exceeding hardware cost). In almost all cases information or data obtained in testing programs must be processed, interpreted, and presented in reports. These activities, which are integral to the typical study in which minicomputers are used, influence the ADPE hardware used in configuring viable systems. At the opposite extreme there are applications which are quite similar in detail but not necessarily subject to the continual modifications, i.e., it may be possible to define all of the necessary hardware and software a priori, develop and test it, and then leave the system more or less alone. In such cases, ease of operation and reliability would be more relevant than are ease of development and flexibility.

7. ADACS require and/or encompass substantially more equipment than would classically be considered to be ADPE. In particular, measurement of various quantities is essential either for their own sake, i.e. the collection of essential data, or for purposes of feedback in process control. Measurement, of course, requires transducers. Measurements made at various locations in the test facility must be transmitted to the data acquisition and process control system either to be archived or processed. The transducers may generate either analog or digital output and the data transmission may be in either digital or analog form. Transmission lines, signal conditioning equipment, and/or form conversion (A/D or D/A) equipment is needed. Similarly, one or more process control mechanisms must be manipulated. This also requires transmission lines, signal conditioning equipment, logic circuits, and form conversion units. Typically, the investment in the digital computer and its peripherals is substantially less than is the cost of the other hardware which comprise the total ADACS. Nevertheless, the computer, as supported by its peripherals, tends to be the heart and brain of the ADACS and therefore warrants critical attention.

Basic Requirements for R&D Systems

8. Described in this section are some of the requirements for

minicomputers and related ADPE to be used in the R&D environment.

9. The Hydraulics Laboratory of WES uses ADACS in an R&D environment where one of the most expensive aspects of ADPE use is program and/or software development. Hence, there is generally a requirement that ADACS be comprised of components which lend themselves to rapid adaptation to new circumstances and new software development. Cost of software development is influenced by:

a. Memory size of minicomputer.

b. Availability of a high-speed random access storage device.

c. Speed of I/O devices.

d. Availability of a higher level language.

There are other CE applications of ADPE in process control and data acquisition with substantially less requirement for program and software development. In these instances the economic significance of software development would appear to be substantially less, although this in itself may be deceiving. A good technical answer to the problem of minimizing both hardware and software costs is the prototyping system discussed in the next section.

10. Perhaps one of the most significant phases of the research process is interpretation of test data. There are many situations in which the design or selection of subsequent tests is dependent on an analysis or at least an inspection of results from tests already concluded. It is not unusual that the interpretation be innovative and not follow a completely preordained schedule. Hence, rapid development of analytical and graphical test procedures and results may have a major impact on the time required to complete a study.

11. There is a serious and persistent question in research programs as to what should be done with test results. In particular, in many activities, one cannot be certain that the interpretative analysis applied to the data initially is necessarily that which will ultimately be found to be the most useful or that all of the information which is significant has been gleaned from the raw data. Decisions concerning long-term retention of basic data depend on such factors as the availability of similar data in the future, the cost (if available) of

obtaining it, and the cost of storage. Normally there is a requirement for the archiving of some of the data.

12. Also of significance is the possibility (really a probability) that some of the data obtained in tests will be analyzed on other systems and/or that the results of data analysis accomplished by the ADACS will themselves be further analyzed elsewhere. Therefore, it is important that data archiving be on a portable media.

13. In the preceding paragraphs of this section some of the general requirements inherently associated with the ADPE components of an ADACS system used in R&D have been identified. The actual components which are necessary to realize the system may vary somewhat depending on the availability of pertinent equipment elsewhere at an installation; for instance, graphics could be extremely important to an activity, but assuming that an appropriate offline plotter was available there would not necessarily need to be a plotter included in the ADACS itself. What in fact would be required would be an appropriate graphic support package. Such possibilities are rather atypical and one finds that the usual ADPE components are those shown in Figure 1. Various additional ADPE may be incorporated into the system. In years past, peripheral equipment was relatively more expensive than it is now, and earlier

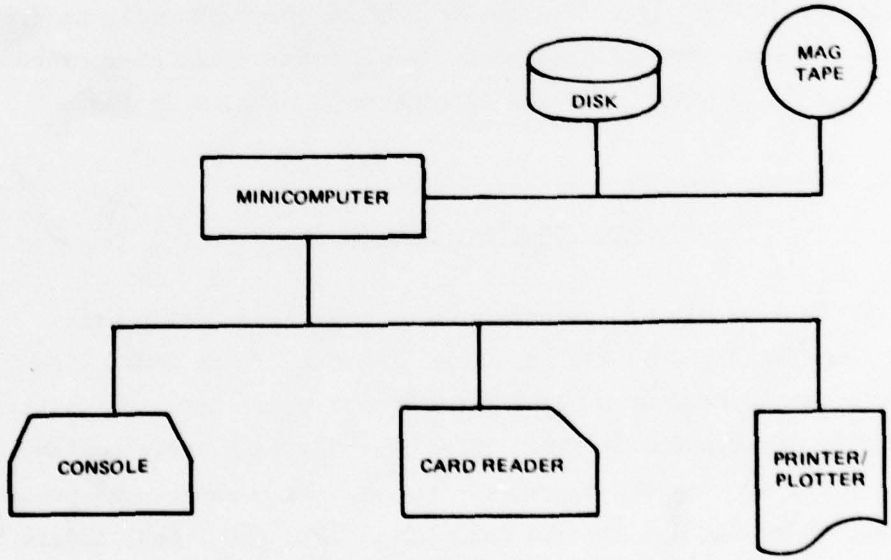


Figure 1. Typical ADPE components of an ADACS

systems were likely to use a model 33 typewriter instead of the console, card reader, and printer shown. Because of long I/O times, this was and is a false economy in most instances where program development and/or data analysis is to be accomplished.

14. The general observations which should be drawn from the discussion in this section are that the minicomputer employed in an ADACS or similar data acquisition and/or process control system may end up being used for program development and at least some data analysis in addition to its primary function of control. Somewhat larger and more expensive systems may be needed or at least be cost effective when program development is to be accomplished on the system. Systems which have enough memory and perephials to facilitate economic program development may also be capable of supporting data analysis and be used economically in this capacity.

15. As employed by the WES Hydraulics Laboratory, the minicomputer is a general purpose tool used to accomplish a variety of specific tasks to which a large general purpose computer would be ill-suited in terms of cost effectiveness. We have not experienced a large enough volume of like applications to make the development of special purpose digital processors economically attractive. Applications areas such as field data acquisition where power consumption and not speed is critical are causing us to become more interested in microcomputers and microprocessors. Cost of development is a significant consideration in these areas.

Developmental Systems

16. It is interesting to begin this section by reviewing the situation that developed in the Estuaries Division of the Hydraulics Laboratory several years back. The Estuaries Division made the initial implementation of an ADACS at WES. There were always major electromechanical problems with the system and the situation had become prohibitive. Also, there was a desire to automate several additional models that had the same fundamental process control and data acquisition

requirements as did the New York Harbor model which was the first model automated. The various models were widely separated and the expense and technical difficulty of transmitting low-level analog signals to a centralized computer seemed excessive. The possibility of installing an ADACS at each model site was therefore investigated. It was found that the minimal ADPE which would be required at the site would be a minicomputer, a high-speed storage device, and an operator's console. Cost per system was estimated at $15,000 which was regarded as reasonable.

17. The complex of local systems (as a group but not individually) needed the type of more general ADP capabilities delineated in the preceding section. Hence, there was a requirement for a single system for prototyping and program development. The concept has since been extended so that the Waterways Division also now operates local low-cost ADACS supported by the more expensive and complex developmental system; and as ultimately implemented, a more powerful minicomputer particularly well-suited to data analysis was added to the developmental system. The two minicomputers share peripherals. A schematic of the system, which is called a development and analysis system, is shown in Figure 2.

18. An additional comment about the concept of using a central system for development and analysis and smaller local ADACS is appropriate. Development of process control and data acquisition software requires specialized skill and knowledge of the hardware being used, whereas ADACS system operation can be done by personnel with only nominal training (in fact, technicians). Hence, the investment in training, labor costs, and equipment are all substantially less than would be the cost for totally independent systems.

19. As indicated at the end of the preceding section, there are some applications in which speed is not critical and it is feasible to apply microcomputers and/or microprocessors. A prototyping system is almost indispensable in developing software for the implementation of microprocessors in specialized applications. The necessity of data acquisition at remote installations where electrical power is not available provides the major emphasis for the utilization of microprocessors.

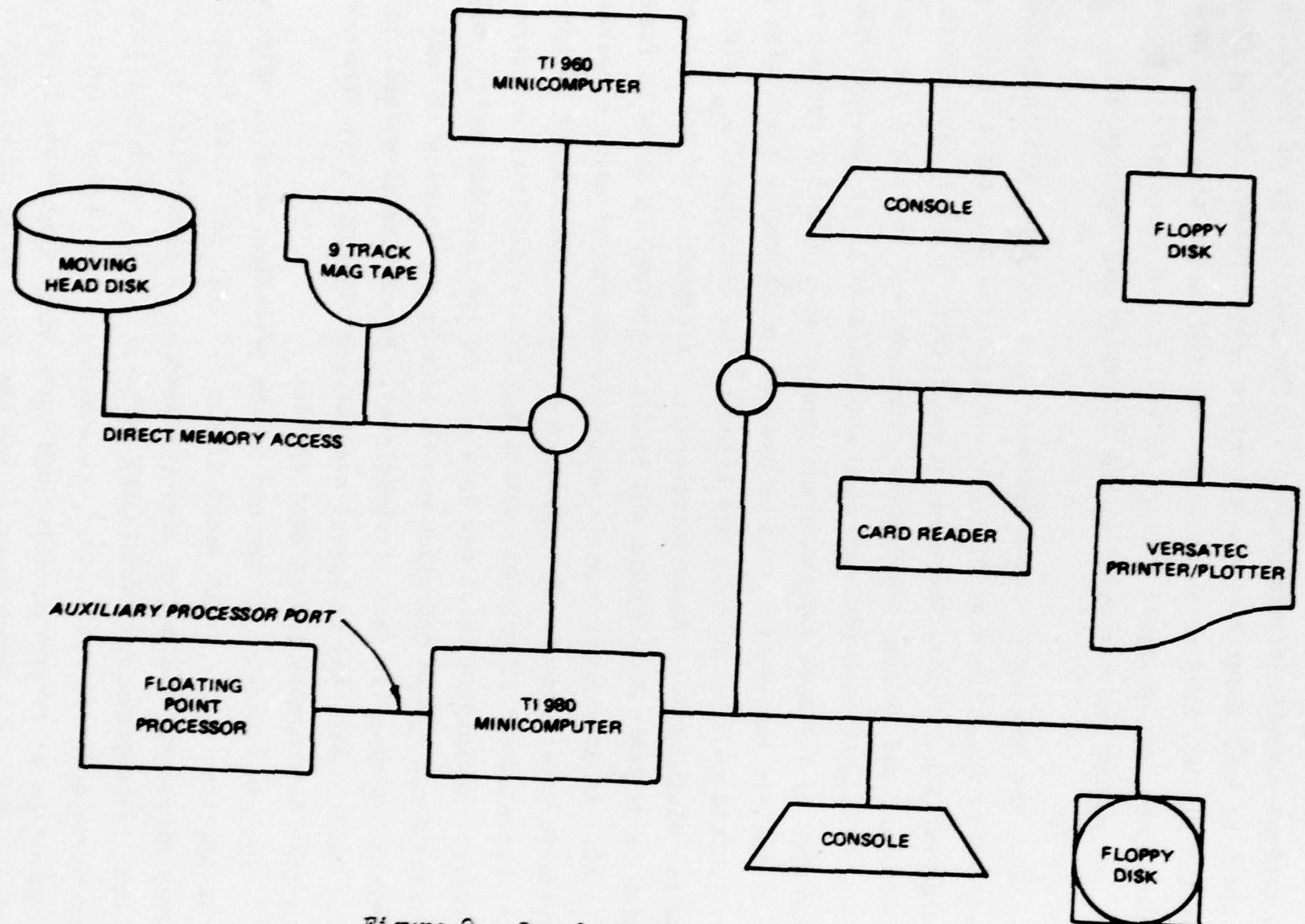


Figure 2. Development and analysis system

It is recognized, however, that once such devices are adapted for a particular requirement, there will be many other uses found for them. Facilities for development are perhaps more essential for microcomputers than for minicomputers.

Minicomputer Components

20. A simplified block diagram corresponding to some of the less sophisticated minicomputers on the market is shown in Figure 3. Some comments about the components of a minicomputer are significant. Some contemporary microprocessors incorporate the register file, arithmetic logical unit (ALU), and microcontroller into a single chip. Also the minicomputer shown has both ROM (read only memory) and RAM (random access memory-read/write).

21. ROM memory may not be written into by the computer but must be programmed by special devices. Three types of ROM's are available: the classic ROM, the field programmable ROM or PROM, and the erasable field programmable ROM or EPROM. The most significant characteristic of ROM's is that they provide a nondestructive storage media. ROM's are used to store microinstructions or in lieu of general purpose memory. In the latter instance, these devices are particularly useful when the computer is to be dedicated to a specific application where permanent storage of the computer program is desirable or where it is desirable to store some function permanently in the computer memory. As an example, the interfacing of a Texas Instruments (TI) minicomputer and a Sykes Floppy Disk was accomplished at WES as a part of the development of the local or satellite ADACS previously discussed. One of the fundamental software requirements was a floppy disk loader. This loader was developed and tested. Initially the loader was stored into memory through the minicomputer's switch panel. It takes a considerable amount of time to enter a program in this way and also the possibility of an erroneous entry is ever present. To alleviate these problems, the loader was stored in ROM and may now be executed automatically. As another example BASIC interpreters are commonly stored in ROM for

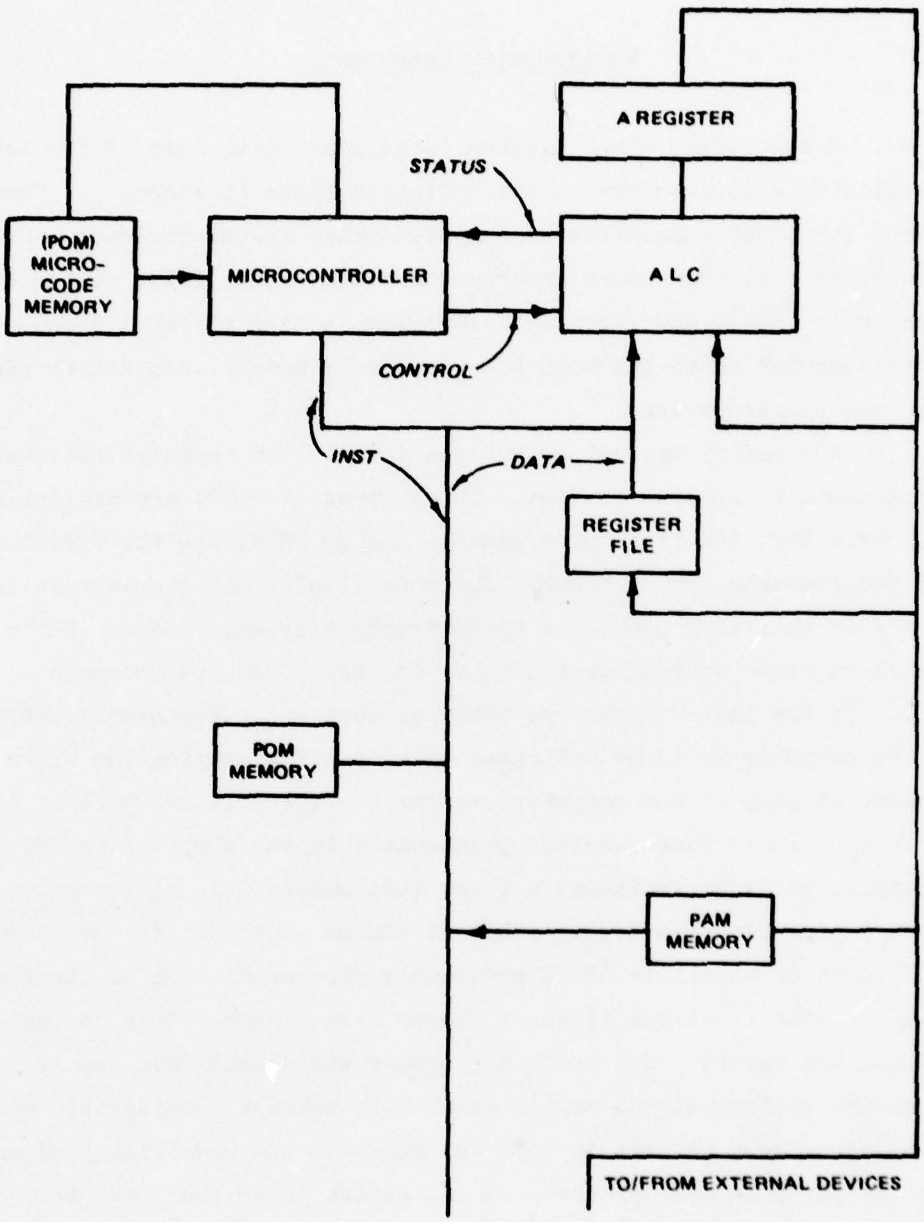


Figure 3. Minicomputer simplified block diagram

microprocessors. We see a major benefit in the future use of ROM program storage in field applications. In particular, ROM program storage makes the minicomputer easier to use and reduces the training of operations personnel accordingly. Such use will in some cases also reduce the amount of peripheral equipment needed in an application.

22. Most minicomputers, as now designed, function by fetching instructions from memory. Each instruction is then broken down into a sequence of microinstructions which the ALU can execute in a clock cycle. Commonly the microinstructions are stored in ROM. As an example consider the instruction

$$R_1 \leftarrow R_1 + R_2 \text{ (add the contents of register } R_1 + R_2 \text{ and store the result in } R_1\text{)}$$

The corresponding microinstructions would be

$$A \leftarrow R_1 \text{ (move } R_1 \text{ to the accumulator)}$$
$$A \leftarrow A + R_2 \text{ (add } R_2\text{)}$$
$$R_1 \leftarrow A \text{ (store the accumulator in } R_1\text{)}$$

Some computers have a fixed instruction set, i.e., the contents of the microcode memory is not meant to be field-modified whereas some devices are microprogrammable. Still other computers store microcode in such a way that the user may extend the instruction set as necessary. A proportional controller, as described in a later section of this report, represents a relatively simple algorithm, and it is feasible to realize the proportional controller as a device consisting entirely of a ROM microcode memory, ALU, and register file. Such devices are, in fact, in common industrial and commercial use at this time.

23. RAM memory may be either static or dynamic, and both types have been used successfully in ADACS applications at WES. The advantage of dynamic semiconducter memory is lower cost. Error correction techniques are believed to be essential in ADACS when semiconducter memory is used. In situations where power interrupts present a substantial

problem as with unattended field stations, use of static memory is probably justified.

24. Most minicomputers facilitate direct memory access from peripheral devices. Some systems do not facilitate or may be configured not to facilitate concurrent direct memory access by multiple devices. This situation or type of system has been found to be totally unsatisfactory in the environment in which ADACS are used at WES. It has also been found that some operating systems will not facilitate concurrent memory access. This problem has been resolved by the development of appropriate drivers, etc., and has not been found to be a major problem. A basic hardware deficiency is, however, unsatisfactory.

25. Numerical computations seem to be an inevitable part of process control and certainly of data analysis. Relatively efficient floating point hardware is available for most minicomputers; it may cost from $5,000 to $10,000. Some applications may be accomplished without its use, i.e. by software. In other instances, it is relatively essential because of requirements for speed and the complexity of the task involved. To be recognized is the fact that some minicomputers have fixed-point arithmetic hardware which is faster (by a factor of 5, say) than the floating point hardware and tends either to come with the system or as a low-cost option. Many computations may be carried out using fixed-point hardware. Scaling and rounding then become the programmer's problem. This approach is recommended only when computations are simple, speed is critical, and it is essential to keep systems cost to a minimum.

Systems Implementation

26. ADACS are likely to require the integration of relatively specialized hardware and/or the development of special purpose software. Those responsible for planning the system must determine the manner by which the system will be realized. One possibility is that a package with the required capability is commercially available. A second possibility is that a contractor may be hired to develop and integrate the

system. A third possibility is that the system be developed and integrated inhouse. The first possibility is, when applicable, the one which is likely to result in the most expeditious and economic method of getting a system operational. The second possibility is reasonable when the functional requirements of the system may be well defined a priori and where there is little probability of their changing. The third possibility should in most instances be approached with intial caution but may be the only rational alternative when a high probability of systems modification is anticipated, and particularly when all of the functional requirements which could reasonably be expected cannot be defined a priori. This is not an unusual circumstance in the R&D environment.

27. Incorporation of new hardware and/or the development of new software is, under the right circumstances, a relatively routine problem. Success in such endeavors is principally dependent on the availability of personnel who have the appropriate technical skills, training, and experience. (In this respect, it is worthwhile to point out that experience indicates that it may take an otherwise competent engineer from 8 to 10 months to become highly familiar with a new minicomputer system.) Also of extreme importance is the availability of sufficient documentation. Some of the problems which have been encountered in systems integration and development have resulted from lack of documentation and/or errors in the documentation provided.

28. It should be recognized that some hardware integration problems are much more complex than others. WES experience with TI equipment indicates that interfacing to the programmed I/O bus is relatively straightforward whereas interfacing to the direct memory access channel would be much more complex and costly. In addition, peripheral devices themselves incorporate differing levels of built-in controls. In particular, a major criterion for selecting a relatively high speed-low cost peripheral for the satellite ADACS described previously was the anticipated cost and time required for interfacing. A Sykes Floppy Disk was selected because its features and internal controls made the problem minimal.

29. An additional possibility is that the interfacing problem has already been solved. Lacking availability of all of the components essential to a system from a particular source, the possibility of obtaining compatible components from different sources should be examined. To illustrate, the Hydraulics Laboratory was interested in the procurement of a high-speed array processor. No vendor sold such a system but compatible (i.e., interfaces and drivers have been developed and tested) components for the system were available from four sources. No substantive difficulty in integration was anticipated in this instance.

Programming of Minicomputers

30. Nearly all minicomputers have FORTRAN compilers which are more or less satisfactory. Unfortunately, specialized devices which are not supported by the FORTRAN are required to accomplish process control and data acquisition tasks. A substantial part of the non-FORTRAN coding which the Hydraulics Laboratory has done for ADACS is related to I/O.

31. Much or most of the programming of minicomputers a decade ago was accomplished in assembly language. Our current policy is to program as much of a problem as possible in FORTRAN and to use inline assembly language where the FORTRAN is inadequate. There are two advantages to this:

a. Programming cost and/or time may be reduced.

b. Program portability is increased.

32. Operating systems may have an important influence on the difficulty of developing computer codes when I/O problems are involved. In particular an operating system may facilitate I/O only through systems calls to drivers. For many types of applications such a procedure is desirable in that I/O programming through system calls relieves the programmer of a great deal of effort. Also, the aforementioned procedure allows the operating system to protect disk files. However, we have normally found that this operating system feature is troublesome in our area of applications interest. In particular, many devices connected to computers are so specialized as not to warrant the

development of drivers. Systems calls are time-consuming, and may result in the introduction of ambiguity into time-critical processes. Also, the development of a driver is a much more time-consuming process than is inline I/O coding. When a new device is being interfaced to the minicomputer and there are both software and hardware problems to be considered, use of a test program as opposed to a driver is nearly essential. In one instance, we were able to "fake" the operating system so that it would actually allow direct program I/O which turns out to work very nicely. In another case, the problem is unresolved. At any rate, it is our experience that an operating system which facilitates direct program I/O as an option is extemely desirable when the minicomputer is to be used for development and/or in process control and data acquisition.

Data Acquisition

33. There are applications in which the sole purpose of data acquisition is for input to a feedback control loop and there are applications in which at least some of the data is acquired for its own sake. In research activities at WES, the latter situation predominates.

34. The natural questions associated with data acquisition are sampling precision, sampling rate, and time integrity. Timing may or may not be critical or it may be critical in differing ways. In some situations, the pertinent time is measurable relative to the occurrence of a specific event such as the firing of a rocket. In some other situations as in wave mechanics, the phase difference between two or more signals is what is significant. In still other situations such as applied orbital dynamics, the occurrence of specific events in otherwise phase-dependent systems must be accounted for. Another possibility is that the time scale used in the process control and/or data acquisition may be nonstandard with the obvious consequence of a distortion of the systems response in the frequency domain. A third timing consideration is what might be called aperture time which is that time interval in which a measurement is made (i.e., in the real world, measurements

21

are not made at the precise time t but in some time interval $t \pm \varepsilon_A$). These and other timing parameters must be considered in systems design, hardware selection, and computer programming.

35. The effect of aperture time can be analyzed. Suppose the function

$$f(t) = a \cos wt$$

is to be sampled and that instead of sampling at time t the sample is actually taken at time $t - \varepsilon_A$. Then

$$\begin{aligned} f(t + \varepsilon_A) &= a \cos [w(t - \varepsilon_A)] \\ &= a(\cos wt \cos w\varepsilon_A + \sin wt \sin w\varepsilon_A) \end{aligned}$$

which for small ε_A results in

$$\text{Error}_A = f(t + \varepsilon_A) - f(t) = aw\varepsilon_A \sin wt$$

or

$$\text{Error}_A \propto aw\varepsilon_A$$

At this point, it should also be noted that f will not be measured exactly. Suppose in fact that f is an analog signal which is converted to digital with a precision $f + \varepsilon_c$, i.e., the precision for a 12-bit A/D converter would be one part in $(2^{12} - 1)$. It can be shown that

$$E_{A+C} = \varepsilon_c + aw\varepsilon_A$$

Hence, ε_c and $aw\varepsilon_A$ should be of the same order of magnitude.

36. The next timing consideration is sampling rate which introduces the very important aspect of aliasing. Two approaches will be used to illustrate the phenomenon of aliasing. First, suppose that the functions

$$f(t) = \cos(wt)$$

and

$$g(t) = \cos\left[\left(w + \frac{2\pi}{\delta t}\right)t\right]$$

are samples at successive time intervals 0 , δt , $2\delta t$, ... The result is

$$f_n = \cos(nw\delta t)$$

and

$$g_n = \cos(nw\delta t \cos(2n\pi) - \sin(nw\delta t) \sin(2n\pi)$$

but then

$$f_n = g_n$$

or put in words the signal g appears to lie at the frequency w and contaminates or aliases the signal f . We see from this that sampling rate is not a parameter which we are free to choose arbitrarily but depends on the spectral characteristics of the process being sampled.

37. Another significant pair of identities are

$$\cos\left[n\left(w + \frac{\pi}{\delta t}\right) \delta t\right] = \cos\left[n\left(w - \frac{\pi}{\delta t}\right) \delta t\right]$$

$$\sin\left[n\left(w + \frac{\pi}{\delta t}\right) \delta t\right] = -\sin\left[n\left(w - \frac{\pi}{\delta t}\right) \delta t\right]$$

which show that discrete uniform samples of the signals of angular velocities $w + \pi/\delta t$ alias or fold back on signals of angular velocity $w - \pi/\delta t$. These identities lead to the sampling theorem which says in essence that to prevent aliasing at lease two equally spaced samples must be taken at the highest frequency contained in a signal.

38. To illustrate the concept graphically, consider the sketch in Figure 4. The actual process depicted has a low- and a high-frequency component. When the signal is sampled, however, it appears to be the sum of the low-frequency component and a mean upward displacement. In other instances, aliasing may cause amplitude and/or phase distortion.

39. For ADACS, it is very important to note that the physical phenomena and the control mechanism(s) may have distinct frequency response characteristics and both of these must be considered in determining an appropriate sampling rate.

Process Control

40. Process control implies the existence of a mechanism which might be electrical, mechanical, or hydraulic or some combination thereof, which is supplied with a set of inputs and from which some output results. There are two fundamentally different types of process control. The simplest type supplies an input to the control mechanism which, in turn, generates some output. A more sophisticated type of controller measures the output of the mechanism, compares it with a desired output, and makes adjustments based upon the difference between the two. The first situation is known as open-loop and the second as closed-loop control. Schematics of the two types of systems are shown in Figure 5. Also shown is a control system that uses multivariable feedback. The selection of feedback variables for process control systems is not arbitrary. Figure 6 depicts a reservoir in which it is desired to maintain a specified water-surface elevation that varies as a function of time. Obvious inputs into the process controller are the desired and observed water-surface elevations. When only these two inputs are used, the behavior of the system is as shown in Figure 7b. In particular, the system never stabilizes and tends to oscillate at some natural frequency of its own. Another variable which can be used as feedback is gate position. Figure 7a shows how the system responds when this variable is used. This behavior is of course substantially more satisfactory. However, it should be noted that the desired and observed

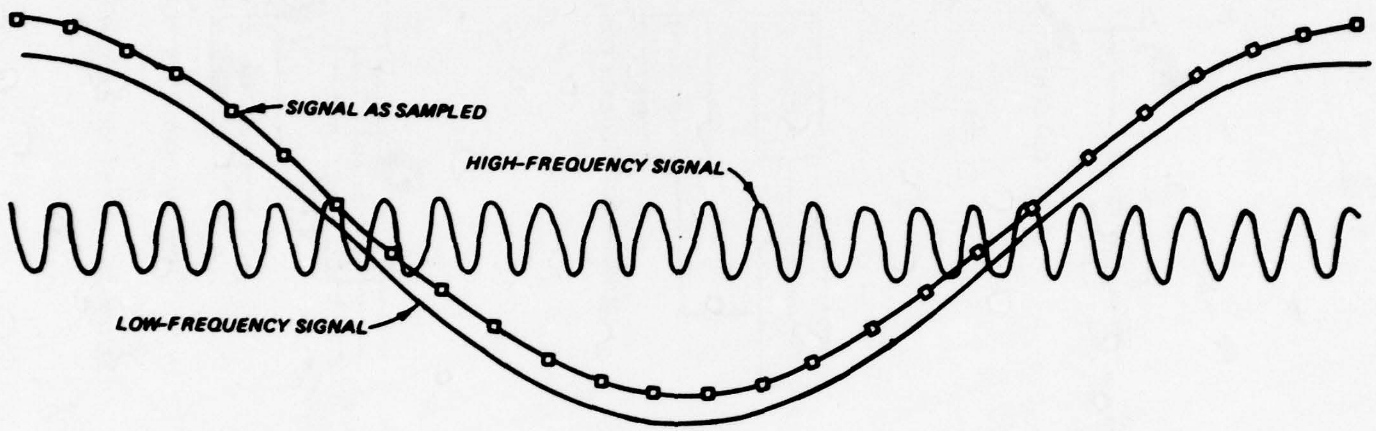
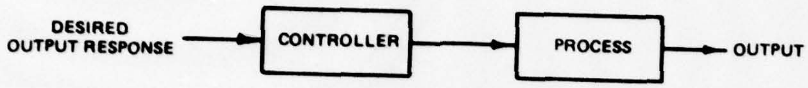
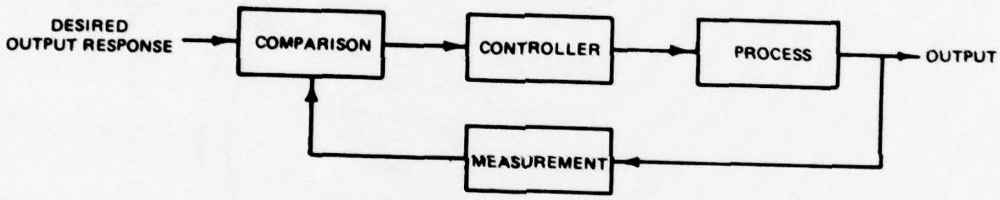


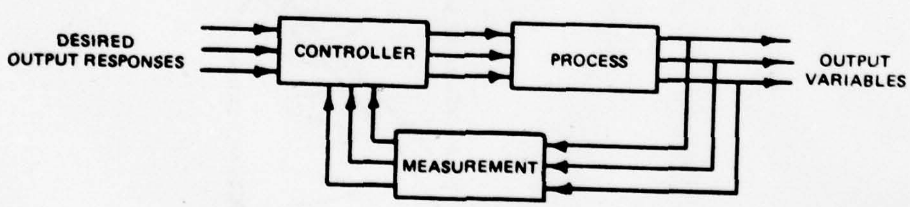
Figure 4. Aliasing



OPEN-LOOP CONTROL SYSTEM



CLOSED-LOOP FEEDBACK CONTROL SYSTEM



MULTIVARIABLE CONTROL SYSTEM

Figure 5. Types of control systems

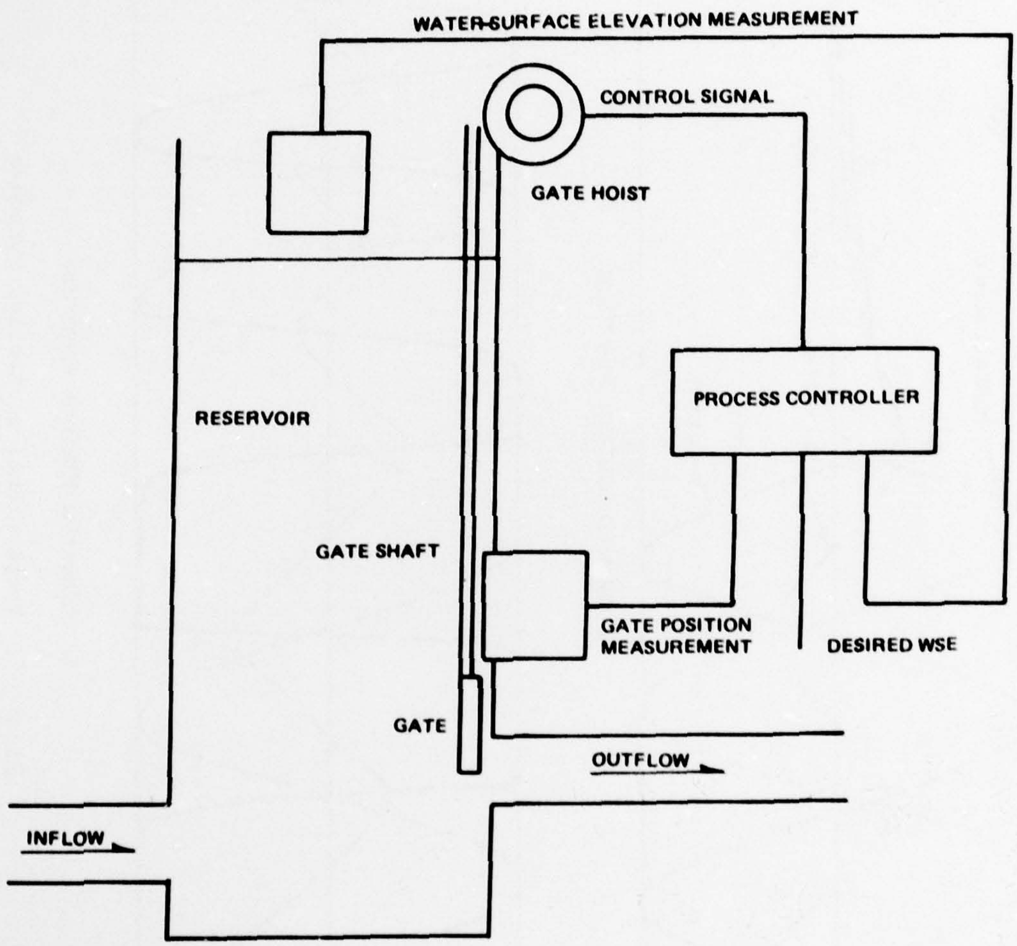
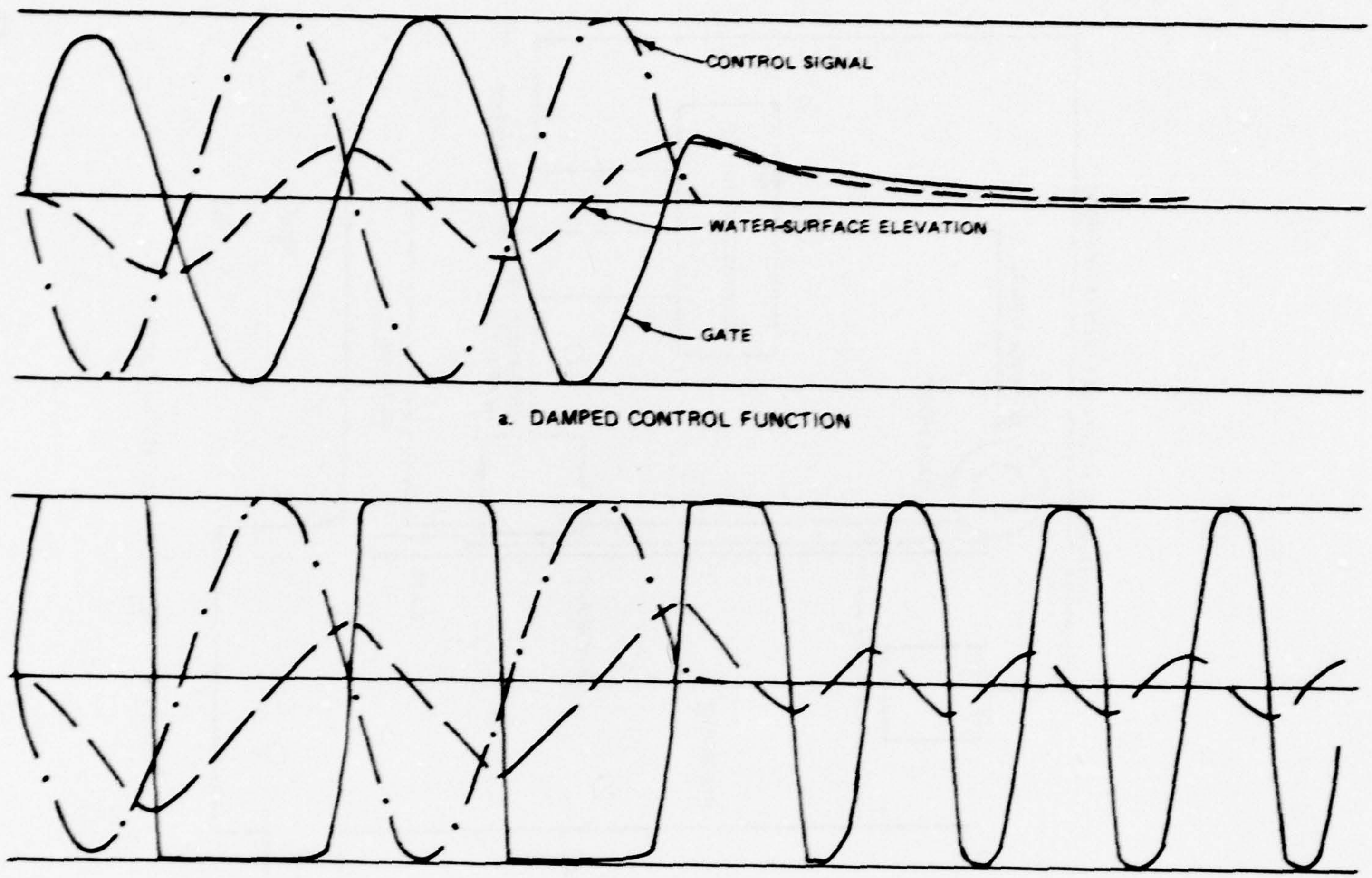


Figure 6. Reservoir control system



a. DAMPED CONTROL FUNCTION

b. UNDAMPED CONTROL FUNCTION

Figure 7. Proportional controller response

water-surface elevations differ substantially. This could be the result either of an improperly tuned control function or of a control mechanism which lacked adequate capacity.

41. The simple control processor known as a proportional controller which was used in the example is shown in Figure 8. It should be noted that there are two multipliers β_1 and β_2 which are constrained only in so far as sign goes, i.e.,

$$\beta_1 < 0$$

$$\beta_2 > 0$$

System performance is limited by the mechanical properties of the system. (For instance, in the example, inflow, maximum outflow, and gate velocity are the important properties.) Unless these properties exceed minimal values which depend on the desired input the desired result cannot be achieved. As the actual mechanical properties approach their minimal values, adequate control becomes sensitive to β_1 and β_2 . A somewhat more sophisticated process controller is the adaptive process controller

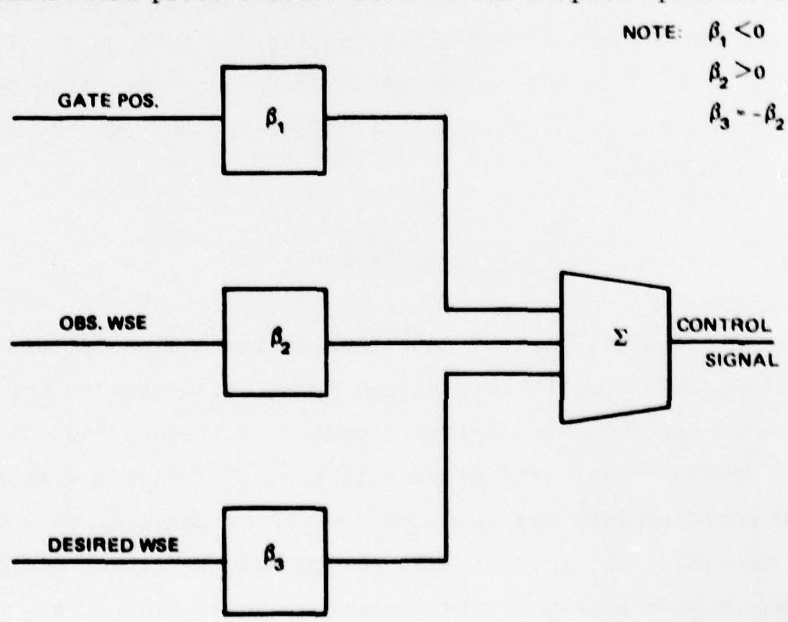


Figure 8. Proportional controller

which learns through experience what values of β_1 and β_2 (in this case) to use. Figure 9 shows an adaptive process controller and Figure 10 the results of applying it.

42. It should also be recognized that electromechanical systems are subject to drift. Hence, the optimal values of β_1 and β_2 may be time-dependent. The adaptive process controller is thus also advantageous in that is has an inherent capability to compensate for such fluctuations.

43. The concept of proportional process controllers has been discussed in this section. Such devices may be realized by combining analog components, by the digital computer used in ADACS, or by use of a dedicated microprocessor. The selection of a control network is principally a matter of economics. Process control may represent a substantial computational burden and it may be desirable to use something besides the system's main processor to achieve it. Also, there is the question of system reliability. In particular, it may not be assumed that the main processor will function without an occasional failure. In the laboratory environment, equipment failure results, principally, in downtime and/or the necessity of repeating tests, both of which may be expensive. In field applications the situation may be more critical. There seems to be no relevant encompassing statement other than that the question of redundancy is of substantial importance and must be addressed on a case by case basis.

Data Transmission

44. As an essential part of data acquisition and/or process control activities, data must be transmitted from transducers to the ADACS digital computer and from the digital computer to process control mechanisms. Commonly this transmission is accomplished via electrical cables. The cable network may be either serial or parallel or some combination thereof. The initial measurements may be either digital or analog or, as is more likely at the current state of technology, a combination of both.

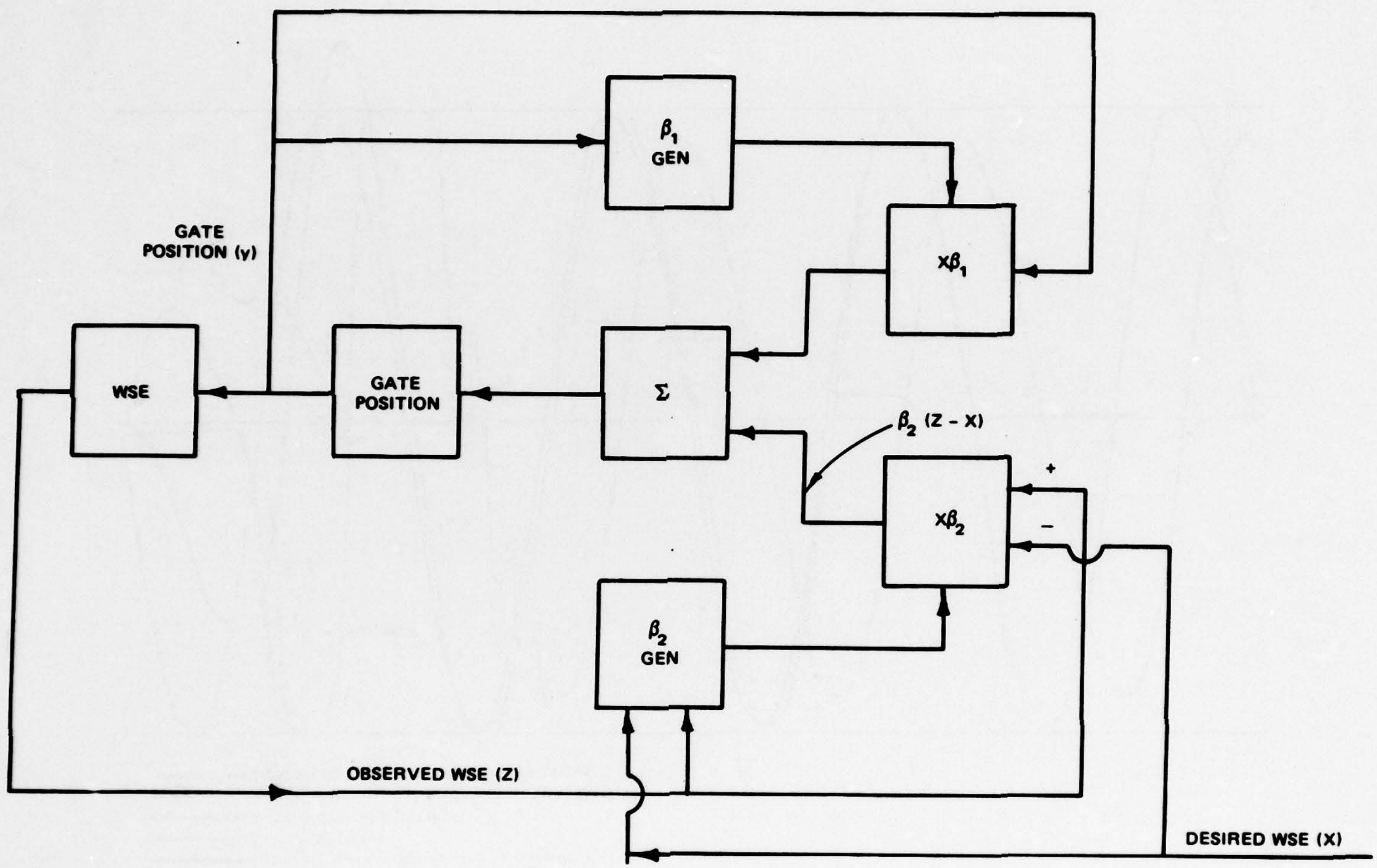


Figure 9. Adaptive proportional controller

37

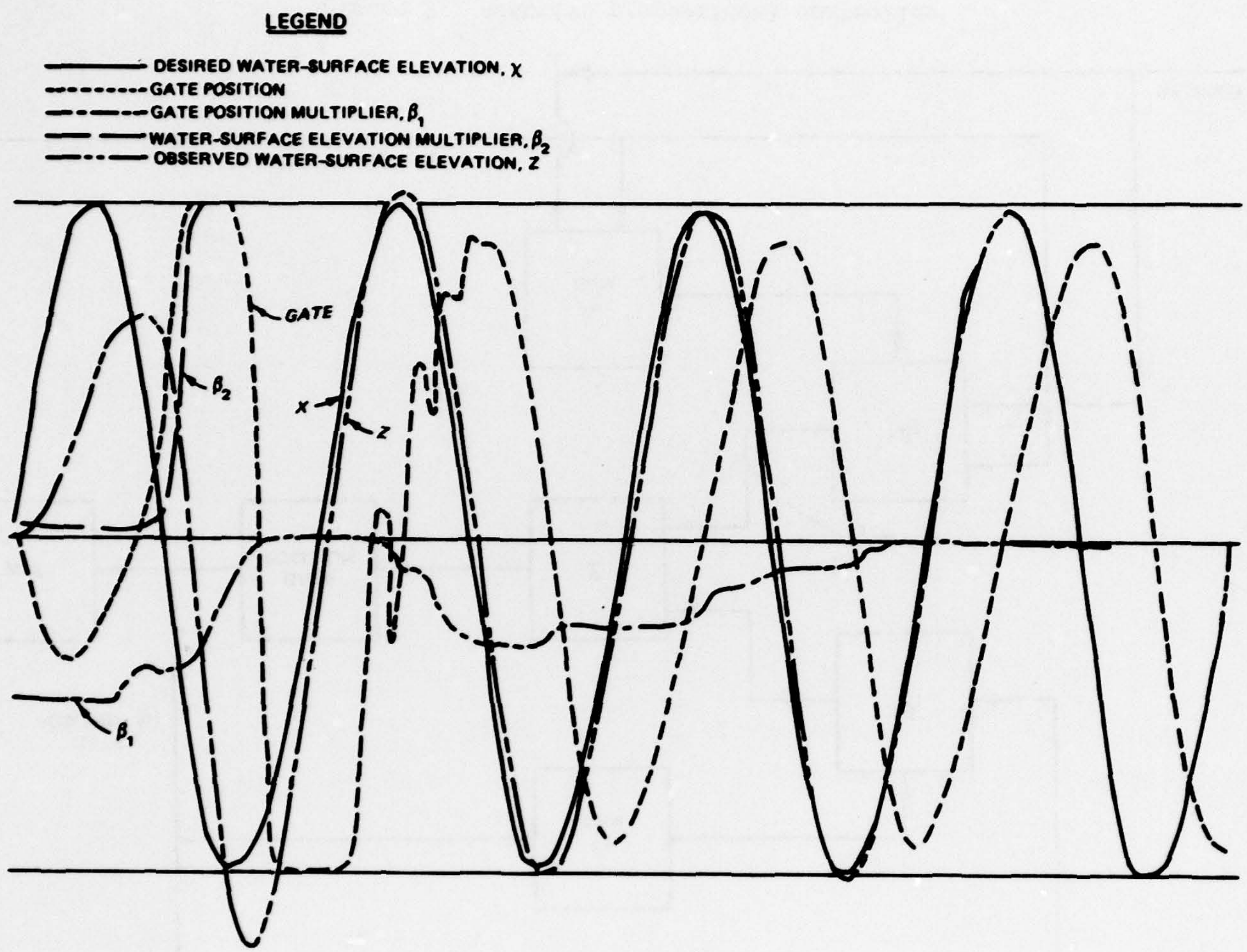


Figure 10. Adaptive proportional controller response

45. Where data are transmitted in analog form it must be anticipated that the signal received by the computer is not necessarily of the same level as it was at the transducer. It may very well be influenced by the physical properties of the line along which it is transmitted and by external noise.

46. A variety of alternatives for data transmission are available. One of these which has recently been implemented will be described. Analog Devices manufactures a set of five modules known as SERDEX or SERial Data Exchange modules which may be used to build up data transmission networks of arbitrary complexity. The modules perform several functions which include

a. Convert the parallel output data from devices such as A/D converters to serial ASCII form that can be transmitted long distances over a single pair of twisted lines.

b. Convert serial ASCII data to parallel form required by digital input devices such as D/A converters.

c. Recognize nine standard ASCII characters that are used to control the modules themselves, and other systems components such as valves and sensors.

47. A simple SERDEX communication system is illustrated in Figures 11 and 12. The basic principle of the system is to send a coded message that sets up a communication link between the computer and a receiver or transmitter. Included in the message is an instruction to the receiver or transmitter and, in the case of a receiver, data which are to be stored in the receiver's internal register. The usual instruction sent to a transmitter is for it to send the data in its internal register back to the computer. Both the receiver and transmitter send back acknowledgments of commands. An additional part of the transmission network developed by WES engineers is a strobe loop. Triggering of this loop causes A/D converters to store digitized values into the transmitter registers and data to be moved from all the receiver registers to the D/A converters. Hence, all A/D and D/A conversions are concurrent and there is no skewing.

48. Most of the control mechanisms and sensors used for feedback are digital. Special purpose digital circuits were designed at WES to

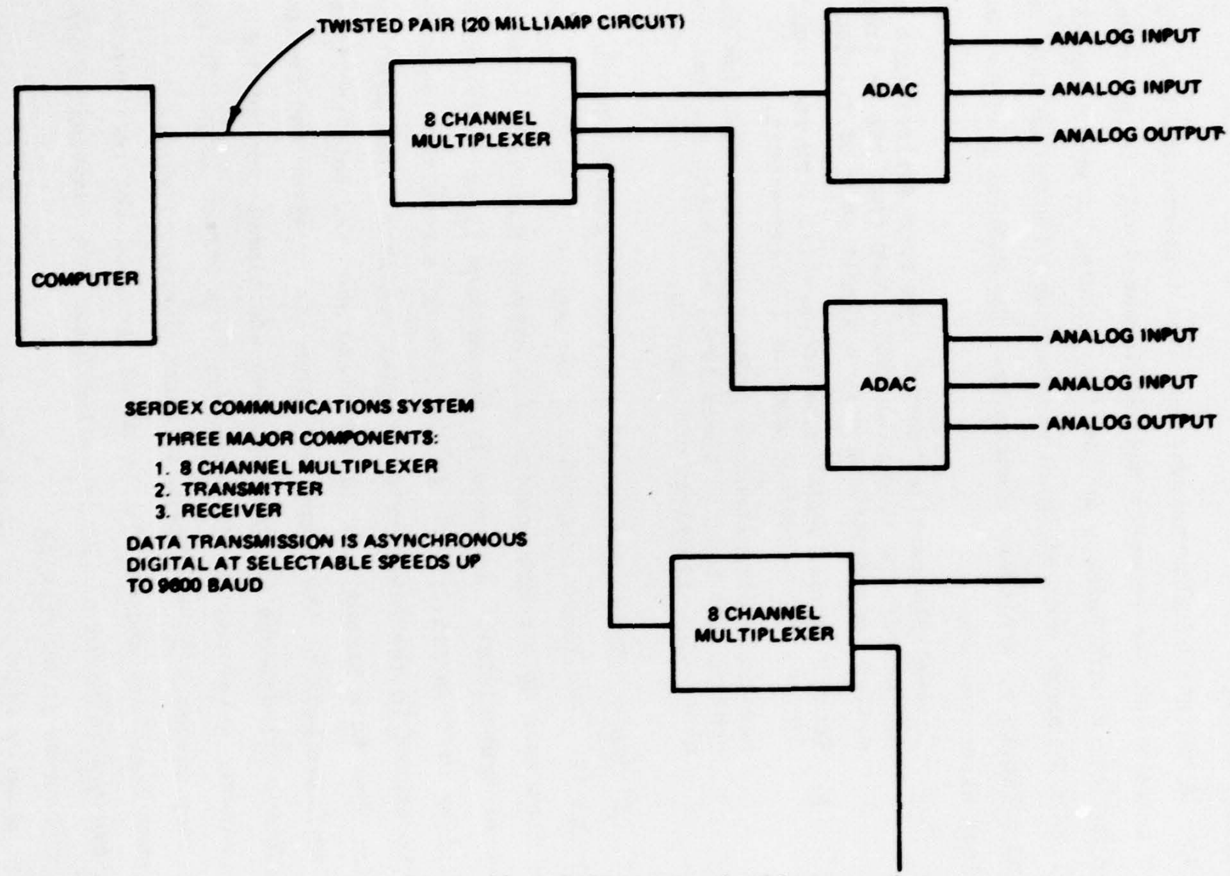


Figure 11. Data communications system

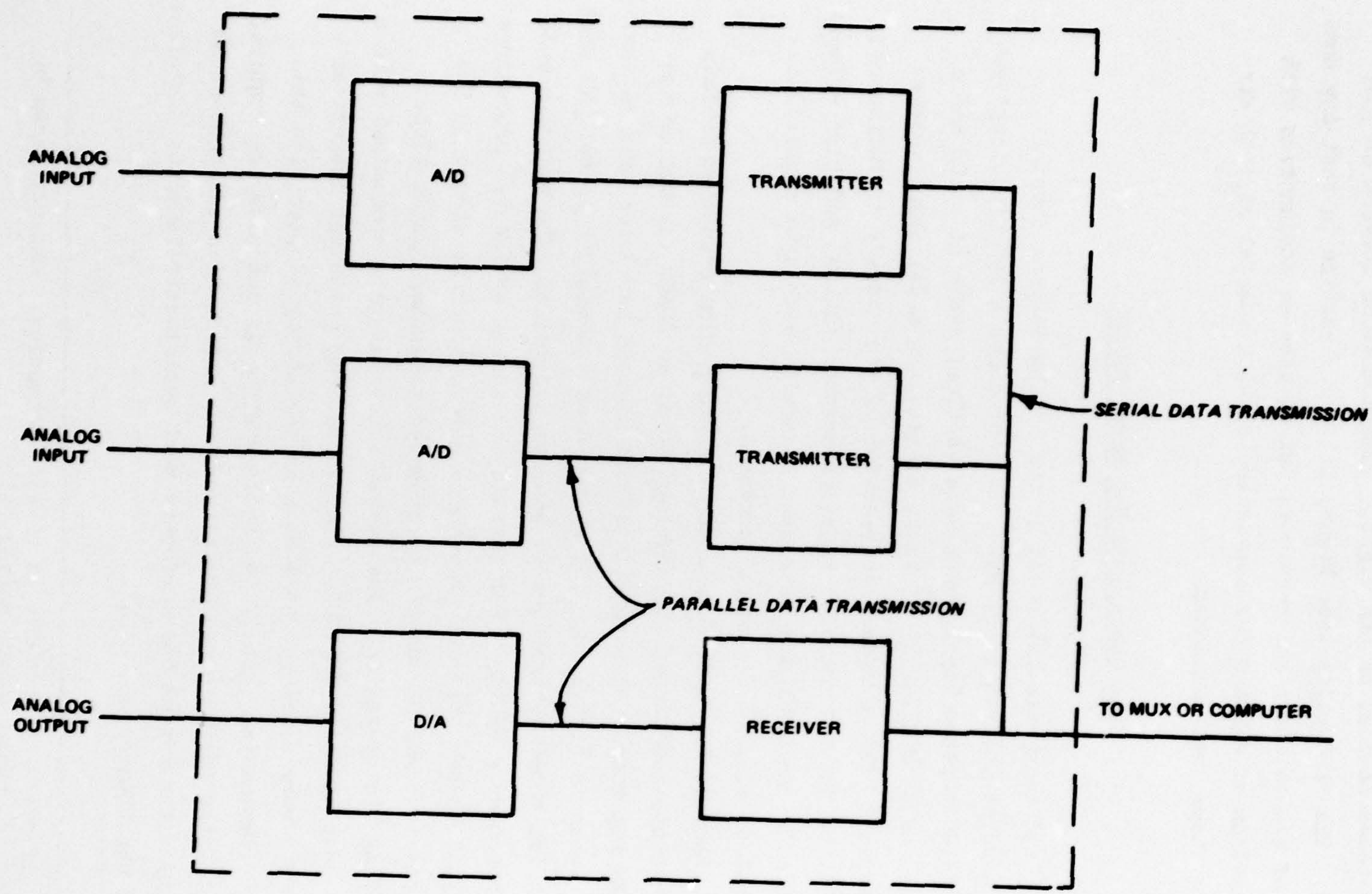


Figure 12. Data acquisition and control unit

interface these devices to the digital communications network as just described. The ADAC units (see Figure 11) are versatile in that any combination of transmitters and receivers may be used in conjunction with any combination of A/D and D/A converters or with special digital circuits like those just mentioned.

The Chesapeake Bay Model ADACS

49. The Chesapeake Bay model is one of the largest physical modeling studies undertaken by WES. It reproduces a 195-mile-long* segment of the Chesapeake Bay Estuary at a vertical scale of 1:100 and a horizontal scale of 1:1000. At these scales, the model itself covers about 7 acres.* The hydrodynamic behavior of the estuary is influenced principally by the astronomical tide, freshwater inflow, and wind effects (not modeled). An ADACS was developed to assist with data acquisition and control of many of the model processes.

50. Many of the considerations of ADACS design presented in this report were applied during the development of an ADACS for use on the Chesapeake Bay model. A schematic of the digital processor used in the ADACS is shown in Figure 13. The system uses two minicomputers: TI 960B to accomplish model control and TI 980B to accomplish data analysis and related computer graphics. Peripherals are shared by the two processors which is not to say that the processors have concurrent access to the devices but that any device can be attached to either system without interrupting its operation. The system was relatively economical with a hardware cost of about $80,000. Special systems component interfaces and software were developed at WES. The philosophy adopted with this particular system was that if the basic system did not have the required capability, the hardware and/or software was modified to add the needed capability. The system has performed very satisfactorily after installation and checkout on the model.

---

* Multiply miles by 1.609344 to obtain kilometres; multiply acres by 4046.856 to obtain square metres.

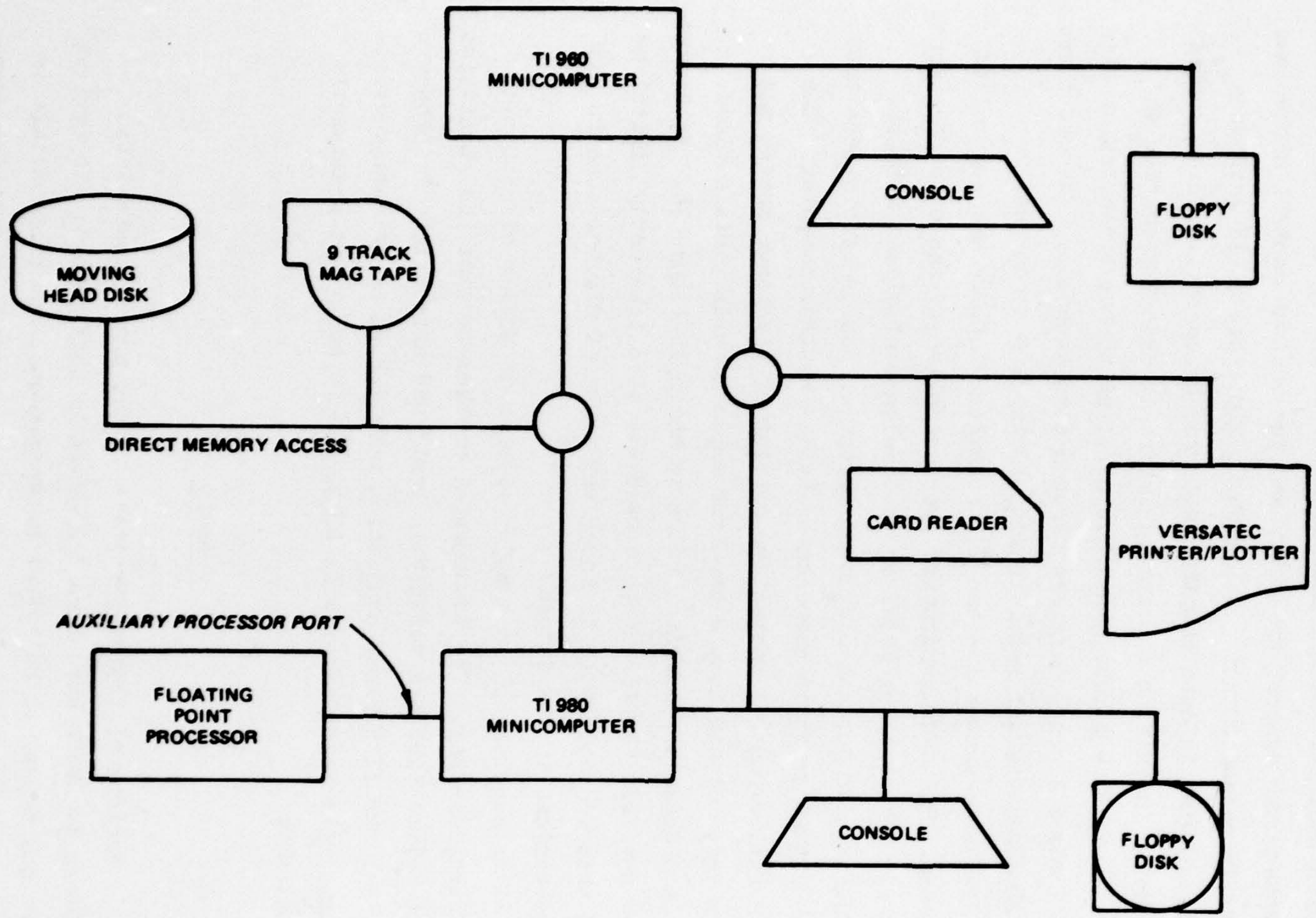


Figure 13. Chesapeake Bay ADACS

51. Data communication is digital using the approach described in the preceding section. Data transmission is serial in that transmission of data between the control processor and the various control mechanisms and sensors is nonconcurrent. Quite obviously, this could introduce undesirable skewing in data sampling and process control. This problem was overcome by installing storage registers at each transmitter and receiver. A separate strobe line runs parallel to the transmission line and all A/D and D/A converters are strobed simultaneously. Hence, there is no skewing because all readings and updates are concurrent.

52. Two tide generators and 24 freshwater inflows are controlled by the system. The tide generators are controlled by analog proportional controllers. The computer provides the analog controllers with the desired source tide surface elevation history. Analog controllers tend to drift and this drift is compensated by the control computer. The freshwater inflow control mechanisms consist of discharge meters and digital valves, Closed-loop control is employed with these devices.

53. A diagram of a digital valve is shown in Figure 14. It should be pointed out that the flow meters used are also inherently digital devices and that we anticipate an increased usage of digital sensors and control mechanisms in the future.

54. Data acquisition is a major problem in models of estuaries such as Chesapeake Bay. The fundamental problem is that the quantities which must be measured are relatively small and appropriate transducers in many cases are either not available, unreliable, or extremely expensive. One of the major efforts in ADACS development must necessarily be in transducers.

Summary

55. A variety of topics pertinent to the proper installation of minicomputers in ADACS have been discussed in this report. In review, the report may appear to be rather heterogeneous, but perhaps this is not unreasonable because a relatively broad spectrum of technical considerations is involved in the design and implementation of ADACS.

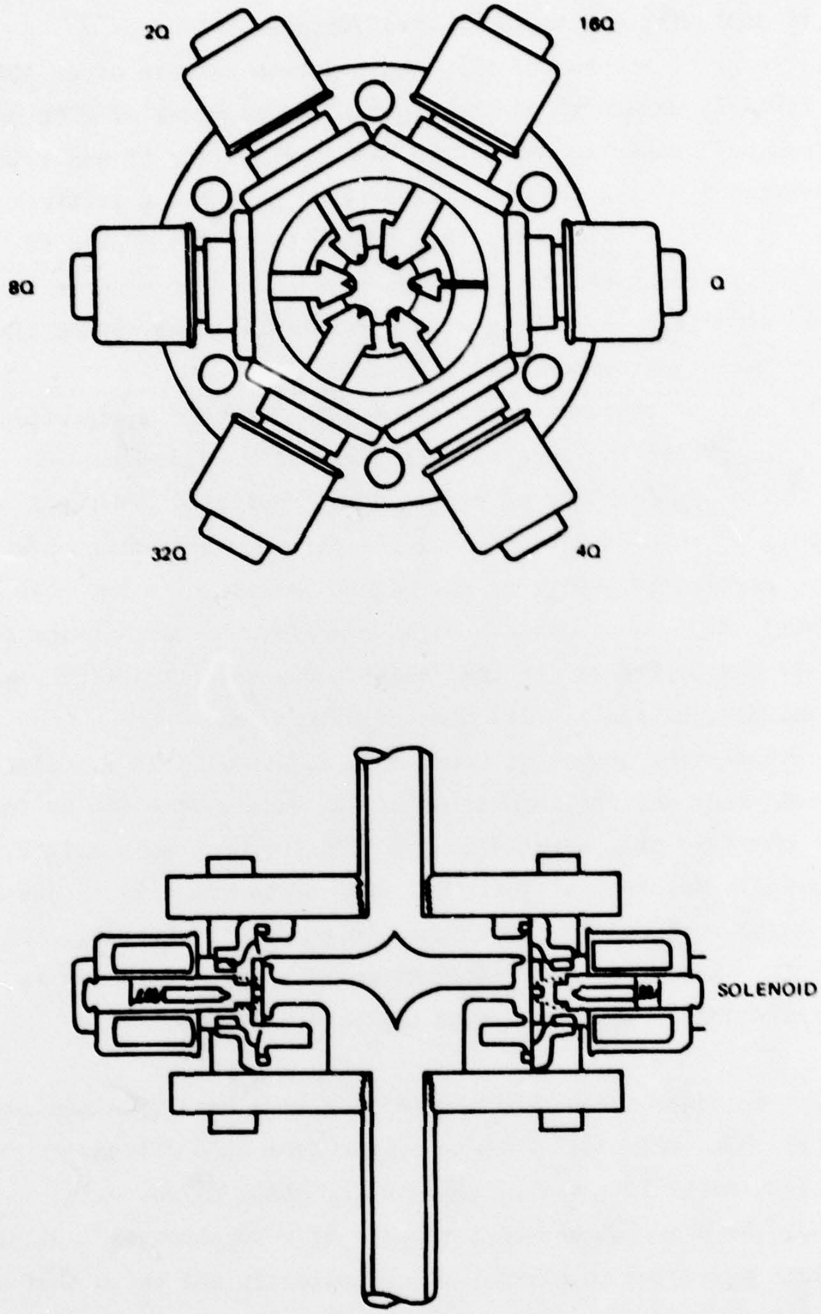


Figure 14. Digital valve

An attempt was made to survey those aspects of the problem which WES had encountered (very often painfully) in practice, while by no means attempting to deal with any topic in great detail.

56. It seems to the author that the ultimate success of an ADACS is not particularly dependent on the specific brand model of ADPE hardware employed, but rather it depends on the availability of qualified technical personnel to the project. Experience also has a critical influence on cost and our opinion is that from 8 to 10 man months of working with a system may be required for an engineer/programmer to become highly efficient in working with a particular combination of minicomputer, operating system, and software.

57. The cost of software development should not be underestimated in that this may exceed the cost of ADPE hardware used in an ADACS application. The availability of experienced, qualified personnel has a major bearing on this expense. Also, peripheral equipment such as card readers, high-speed printers, and magnetic disk units may also impact software development costs. As an example, the compilation of one relatively small program required about a day without the aforementioned peripherals, but only a few minutes with them.

58. A substantial amount of electronic engineering is associated with the development and implementation of ADACS, and it would be infeasible to undertake the installation of ADACS without such skills. Also, it should be pointed out that the ADACS system must be maintained, and that at least some relatively unique equipment will probably be configured into it. An important consideration in project planning is then a determination of how the system may be most economically maintained.

59. Process control and data acquisition were briefly discussed in this report. The principal idea to retain from this discussion is that the design, selection, and programming of ADACS cannot exist in a vacuum but must be accomplished on the basis of a substantial knowledge of the physical phenomena involved. For example, it was shown that unless gate position was used as feedback the proportional controller intended to regulate a reservoir gate would either go into a severe

hunting oscillation or become entirely unstable. Also, data acquisition parameters such as sampling rate cannot be chosen capriciously but are dependent on the spectral characteristics of the signal which is to be sampled.

60. It is somewhat simpler to describe the overall data processing requirements of a given activity than to determine what part of the activity should be accomplished on a specific hardware system. A variety of time and situation variant factors influence the association of specific data processing tasks with particular hardware systems. Certainly the systems designer or systems analyst must be aware of the overall data processing requirement and come to some decisions as to how or where various individual tasks are to be accomplished.

61. Typically the ADACS is ultimately used for program development and data analysis as well as process control and data acquisition. Each of these activities places specific requirements on the system. These requirements tend to be complementary in that more memory and peripherals may be needed for program development than in operation and this "excess" capability may make the system suitable for data analysis, although this is not its primary purpose.

62. Systems reliability is a major question that has been only marginally addressed in this report. The cost and consequences of a system being off the air while awaiting repairs or being repaired should be analyzed in systems analysis. Typically, achievement of systems reliability requires redundancy. A multiprocessor system such as employed by the Estuaries Division and described earlier in this report provides considerable backup although it fails to provide the complete real time redundancy that might be needed in a sensitive application.

63. The basic purpose of this report has been to elucidate typical problems associated with implementing ADACS. The discussion has been centered around data processing requirements of hydrodynamic research and the use of ADACS in physical modeling, which would seem to be somewhat specialized. The basic problems of designing and implementing ADACS for other purposes and in other environments are, however, essentially the same. Hence, the technical skills, design capabilities, and

41

experience of WES can potentially make an increased contribution to the solution of complex engineering problems requiring specialized computers.

64. Finally, it is important that engineering managers recognize that although funding and the availability of good hardware and software are important, the real key to success is proper staffing; and when or if this is not available locally, assistance should be sought from WES or a competent private company.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Multer, Roger H
  Planning of Automated Data Acquisition and Process Control Systems (ADACS) / by Roger H. Multer. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
  38 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; HL-80-1)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

1. Automated Data Acquisition and Control Systems. 2. Automation. 3. Control equipment. 4. Data acquisition. 5. Process control. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; HL-80-1.
TA7.W34m no.HL-80-1